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(71) Applicant: YAMATO SCALE CO., LTD.
5-22, Saenba-cho
Akashi 673 (JP)

(72) Inventor: Inoue, Shinichi
3-1-30 Utashikiyama
Tarumi-ku Kobe 655 (JP)

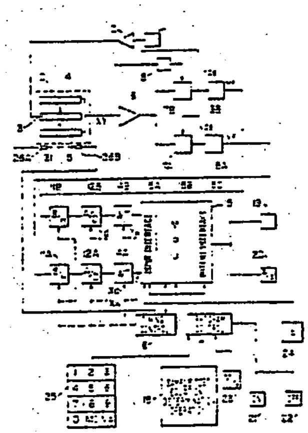
Nakayama, Kazuo
1-15-5-512 Wasaka
Akashi 673 (JP)

(74) Representative: Burke, Steven David et al
R.G.C. Jenkins & Co. 26 Caxton Street
London SW1H 0RJ (GB)

(54) Foreign matter detector.

(57) A foreign matter detector includes an oscillator (1) coupled to an electromagnetic transducer (10) which includes an excitation coil (3) connected to the oscillator (1) and two interconnected detection coils (4,5) adapted to produce a differential signal therebetween when an object is passed through the transducer. A first detector (7A) produces an analog signal corresponding to the component of the differential signal in phase with the oscillating signal, and a second detector (7B) produces a second analog signal corresponding to the component of the differential signal in phase with a phase-shifted version of the oscillating signal. The analog signals are converted to digital signals. As the object passes the transducer, the output of the transducer changes in a first sense during a first part of the passage and in the opposite sense during the remaining part of the passage. A photosensor (50) generates a passage signal which lasts for one part of the object's passage through the transducer. The passage signal is used to define the digital values of the two digital signals from which representative values X and Y are selected. These values are used in one or more discriminant equations to determine whether foreign matter has been detected. Coefficients for the discriminant equations are derived by passing sample objects through the detector. The coefficients can be stored, together with a code associated with the type of object being detected, for later retrieval.

FIG.1



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Descripti n

FOREIGN MATTER DETECTOR

Background of the Inv ntion

This invention relates to a detector for detecting in food products, pharmaceutical products, etc. the presence of materials such as metals, which must not be present in the product and which have a different quality from the inherent or standard quality of the actual product.

For manufacturers of food products, etc., the presence of foreign matter in raw materials could cause damage to processing equipment. Also, the presence of foreign matter in finished products poses problems with regard to health and safety of the products. For this reason, detectors have long been used for inspection at the point where raw materials for such products are supplied to processing equipment and for inspection at the shipping point of wrapped finished products in order to find any foreign matter.

This type of conventional detector includes an electromagnetic transducer as shown in Fig. 19 or 20, which is essentially the same as a differential transformer. The transducer has a primary or excitation coil 3 generating an alternating electromagnetic field when a high-frequency electrical current is supplied, and a pair of secondary or detection coils 4 and 5 electromagnetically connected to the coil 3.

The secondary coils 4 and 5 are wound in opposite directions from each other and interconnected in series so that they operate differentially. The voltages or currents induced in the secondary coils cancel each other out or offset each other. This forms means for detecting the difference in the signals induced in the secondary coils.

In Fig. 19, the primary coil 3 is wound between and coaxially with the secondary coils 4 and 5. In Fig. 20, the primary coil is wound in parallel planes with the secondary coils.

The transducer utilizes the following phenomena which occur when an object being inspected is passed through the magnetic field in the direction 31.

If the object contains iron, the magnetic flux density will increase. The induced voltage of the secondary coil 5 adjacent the passing object will first become higher than that of the other secondary coil 4. If the object contains a nonferrous metal, the eddy current occurring in the metal will cause a loss of the lines of magnetic force. As a result, the induced voltage of the secondary coil 5 will first become lower than that of secondary coil 4.

Some food products may contain water or salt which may generate a relatively large signal, for reasons similar to those in the case of nonferrous metal, even though the products contain no foreign matter. This signal represents the product characteristics of the material, which are called "material effect".

If ferrous or nonferrous foreign matter is contained in these materials, the combination of the signal from this foreign matter and the product characteristics result in a composite signal.

If the foreign matter is small, the signal resulting from it will be small, and there is little difference between the signal generated by the product characteristics of the product itself and the combination of this signal and that caused by the foreign matter. This makes it difficult to detect the foreign matter.

It is in consideration of problems such as this that detectors such as that described in Japanese Patent Provisional Publication SHO.57-198880 have been proposed.

In the publication, the oscillation signal from an oscillator is supplied via a phase shifter to a transducer 4, which outputs a differential signal when an object passes through the transducer. This output signal is detected by a first chopper synchronized with the oscillation signal to obtain an in-phase chopped signal, and by a second chopper having a phase difference of 90 degrees from the oscillation signal to obtain a quadrature chopped signal. Each chopped signal is filtered and independently compared by a level comparator.

With this detector, to detect foreign matter in products having material effect, by adjusting one of the choppers to the phase at which the influence of the material effect is minimized (the phase 90 degrees from the phase angle at which the material effect is maximized), a detection signal with good sensitivity to the foreign matter can be obtained.

However, in order to reduce the material effect value to a level one-tenth or less that of the maximum value, it is theoretically necessary to keep the allowable error angle of the phase adjustment within approximately 6 degrees from the optimum phase angle. In other words, for the actual detection of foreign matter, in order to limit the material effect value to a level which does not influence practical use, for example, to a level within 3% of the maximum material effect value, it is necessary for the allowable error angle of the phase adjustment to be within approximately 1.8 degrees. Thus, precise trial-and-error adjustments are required in order to detect foreign matter in products having a large material effect.

In addition, for the level setting of the level comparator which will be explained later, it is necessary to adjust the sensitivity or gain to obtain an appropriate level corresponding to the phase adjustment just described. Thus, for this detector, the operator is required to perform skilled trial-and-error adjustments for the setting of the two variables of the phase adjustment and the sensitivity adjustment.

In addition, even if the detector is adjusted as described above, it is necessary to give a large reference level in advance for offsetting the material effect for foreign matter producing a signal in the same direction as that

of the material effect. Consequently, in this phase direction, the detector is used in a condition in which the sensitivity has been sharply reduced. Consequently, less detection effectiveness can be expected for metals and other foreign matter in this phase direction.

Summary f th Inv ntion

In consideration of the conditions described above, the objective of this invention is to propose a detector for detecting the presence of metals and other foreign matter which does not require the operator to perform skilled trial-and-error adjustments such as the two factors of the phase adjustment and the sensitivity adjustment, and which is capable of detecting with good-sensitivity foreign matter having a phase direction the same as or close to that of the material effect.

A detector according to this invention comprises:
means for providing a two-dimensional pair of analog signals representative of electromagnetic parameters of an object;
means for converting said analog signals respectively into two series of digital values;
means for determining a pair of representative values each among one of said series of digital values; and means for comparing said representative values with reference values.

Brief Description of the Drawings

Fig. 1 is a block diagram of a detector according to the invention;
Fig. 2 is a block diagram of each of the weighting circuits in the detector;
Figs. 3a-3c show analog signals at various stages in the detector;
Fig. 4 graphically represents digital values from one of the A/D converters in the detector;
Figs. 5a-5c graphically represent various weighting functions;
Fig. 6 graphically represents weighted digital values from one of the weighting circuits;
Fig. 7a also shows digital values, but obtained when two objects are passed in succession through the transducer in the detector;
Fig. 7b also shows weighted values, but obtained by weighting the values of Fig. 7a;
Fig. 8 is a flowchart of a program for determining primary values;
Fig. 9 shows monitoring of the weighted values to obtain a primary value;
Fig. 10 is a partial schematic view of a modified detector according to the invention;
Fig. 11 is a block diagram of a circuitry used with the detector of Fig. 10;
Figs. 12a and 12b show signals at different points in the modified detector;
Fig. 13 is a two-axis, four-quadrant coordinate system showing vectors which represent the detected values and types of metal;
Fig. 14 is a two-axis, four-quadrant coordinate system representing data for objects having material effect;
Fig. 15 is a two-axis, four-quadrant coordinate system representing data for objects having no material effect;
Fig. 16 is a two-axis, four-quadrant coordinate system showing the relationship between the correlation coefficient and the region determined by a discriminant equation according to the invention;
Fig. 17 is a two-axis, four-quadrant coordinate cystem showing the region determined by another discriminant equation according to the invention;
Fig. 18 is a flowchart of a program for determining and indicating whether the primary values are in or outside a predetermined region;
Figs. 19 and 20 schematically show conventional electromagnetic transducers.

Corresponding reference characters indicate corresponding parts throughout the several views of the drawings.

Detailed Description of Preferred Embodiments

In Fig. 1, an oscillator 1 generates a basic sine-wave electrical alternating current signal having a high frequency which is selectable within a range of 30 to 400 kHz.

An electromagnetic transducer 10 is essentially the same as the conventional transducer shown in Fig. 19, and may otherwise be constructed as shown in Fig. 20.

The transducer 10 has a primary coil 3 connected through a first terminal with the output of amplifier 2, and a pair of secondary coils 4 and 5 for providing a differential signal XY representative of electromagnetic parameters of an object being evaluated.

A photoelectric sensor, which may include a light emitter 26A and a light receiver 26B, is located in front of the secondary coil 5 to detect the passage of the object into the transducer 10.

The output line of secondary coils 4 and 5 is connected through a second amplifier 6 with first inputs of a pair of multiplier/detectors 7A and 7B, which are essentially the same as the four-quadrant wave detectors or product detectors used in FM receivers.

The wave detector 7A has a second input connected with the output of first amplifier 2 to receive the amplified signal as a reference signal in phase with the basic oscillation signal.

The detector 7B has a second input connected through a phase shifter 8 with the output of first amplifier 2 to receive a reference signal out of phase, which is 90 degrees delayed from the basic signal.

The outputs of detectors 7A and 7B are connected through pairs of smoothers/filters 9A and 9B, sample-and-hold circuits 11A and 11B, analog/digital converters 12A and 12B and weighting circuits 14A and 14B with the input interface 15A of a control or computing device 15.

The input interface 15A is connected with the light receiver 26B and a device 24 for inputting a region coefficient as explained later.

The control device 15 includes a microprocessing unit (MPU) 15B and an output interface 15C, which is connected with an alarm 19, such as a lamp or buzzer emitting a warning indication when foreign matter is detected. The interface 15C is also connected with an R/φ indicator 20 indicating the magnitude and phase angle of the data.

A timing control circuit 16 is connected with the sample-and-hold circuits 11A and 11B, A/D converters 12A and 12B, weighting circuits 14A and 14B and control device 15, to operate them in synchronization.

A program control circuit 17 is connected with the control device 15, an execution (ON) button 21 which initiates operation of the control device 15, and a stop (OFF) button 22 which terminates it.

The program control circuit 17 is also connected with a selector switch 18 for selecting one of the modes "sample test", "equation determination" and "operation" and another switch 23 for selecting one of the sample modes "M" and "N" explained later.

The program control circuit 17 is provided with a keyboard 25 to store data for a type of object and use it for subsequent inspections. The keyboard 25 has numeric keys for specifying a code number to label the type of object after collecting the data, a command key Mi for storing the data in the memory of MPU 15b, and a command key Mo for recalling it.

As shown in Fig. 2 (and the applicant's European Patent Appln. No. 89303673.1 filed on April 13, 1989), the weighting circuits 14A and 14B each comprise a predetermined number of stages of delay elements 141, which are connected in cascade or series, and which may be a shift register.

The inputs of elements 141 and the output of the last element are connected through coefficient multipliers 142, respectively, with a summer 143 such as a counter.

The circuit of Fig. 2 is a non-recursive type circuit, and may be what is commonly known as an FIR (finite impulse response) filter. The weighting circuit may be replaced by, for example, a 16-bit microprocessor or a commercially available multiplier/accumulator designed for digital computations.

SIGNAL DETECTION AND WEIGHTING

With reference to Fig. 1, when an object containing iron, for example, is passed for inspection by a belt conveyor (not shown) through the transducer 10, the electromagnetic induction formed between the primary coil 3 and the secondary coils 4 and 5 changes as the object passes. An induced voltage XY in a waveform as shown in Fig. 3a is generated as the differential signal from the transducer 10.

The differential signal XY is amplified by the second amplifier 6, and then detected by the wave detectors 7A and 7B by multiplication by the in-phase and out-of-phase reference signals, respectively. The detectors 7A and 7B output signals Xde and Yde in waveforms as shown in Fig. 3b.

The detected signal Xde corresponds to the component of differential signal XY which is in phase with the basic oscillation signal, while the signal Yde corresponds to the component of signal XY which has a 90 degree phase delay from the basic signal.

The detected signals Xde and Yde are filtered by the associated smoothers/filters 9A and 9B to be signals Xf and Yf with waveforms as shown in Fig. 3c, which are temporarily stored in the corresponding sample-and-hold circuits 11A and 11B.

The stored analog signals are converted to digital signals Xdi and Ydi by the corresponding A/D converters 12A and 12B at regular intervals, and input to the corresponding weighting circuits 14A and 14B, which perform weighting processing characterized by a time distribution as will be explained in detail below.

Referring to Fig. 4, the signal Xdi, for example, as a discrete series of digital values $x(0)$, $X(T)$ ... $X((n-1)T)$ is input to the weighting circuit 14A at sample time intervals T. (For convenience, this explanation uses zero as the time of the first value $X(0)$.)

Each weighting circuit 14A, 14B has a pulse transfer function for weighting which is a series expressed as a polynomial relating to Z^{-1} to the order n-1, the number n being odd, as shown in the following Equation (1).

$$H(z) = K_0 + K_1 z^{-1} + K_2 Z^{-2} + \dots K_{n-1} Z^{-(n-1)} \quad (1)$$

Referring to Fig. 2, the number n of multipliers 142 are assigned weighting coefficients Ko to Kn-1 which are distributed in the form of an odd function, as shown in Fig. 5a, 5b or 5c. The coefficients have a point-symmetrical distribution, and the central coefficient for the central multiplier 142 is located at the origin point of the odd function.

The triangular distribution of Fig. 5a is the reverse form of a typical waveform, which resembles Fig. 4,.

representing the signal change with time when iron passes through the transducer 10. The number n is determined experimentally according to the duration of the typical wave. The distribution of Fig. 5b takes the form of a doublet sine wave, and that of Fig. 5c is rectangular.

The duration of function H(z) is most preferably substantially the same as the period for which a typical material, such as iron, passes through the transducer 1.

When the digital signal Xdi in the form shown in Fig. 4 is input to the weighting circuit 14A, a time series of weighted signal values Xw as shown in Fig. 6 are output. Weighted values Yw are obtained in the same way from the weighting circuit 14B.

Thus, a digital signal with the polarities shown in Fig. 4 input to the weighting circuit 14A or 14B will produce a weighted signal as shown in Fig. 6, which has the following characteristics:

(1) The amplitude of the maximum value is about twice that of the minimum value;

(2) The polarity of the minimum value is the opposite of that of the maximum value; this minimum value appears twice at approximately an interval t1 preceding and following the maximum value; and

(3) The data of the output signal which precedes and follows the central maximum value is substantially symmetrical around that maximum value.

Conversely, if the polarities of the input signal Xdi or Ydi are the reverse of those shown in Fig. 4, an output signal Xw or Yw having the exact opposite polarities from those in Fig. 6 is obtained.

In other words, the output signal from the weighting means, to which an input signal such as shown in Fig. 4 is applied, has the characteristics of a discrete time-series output signal, which is distributed in the form of an even function with the origin point having the maximum value, if the time at which the time-series weighted signal has the maximum value is defined as the origin point of time.

As shown in Fig. 4, the digital signal Xdi, for example, has a form with two polarities, positive and negative (or negative and positive), for a single object.

As shown in Fig. 7a, if two products containing foreign matter are passed through the transducer 1 one after another in close proximity, the signal Xdi will have four peaks P1′-P4′. In this case, a pair of peaks P1′ and P2′ and a pair of peaks P3′ and P4′ should be identified separately for the respective products.

If the signal Xdi were not weighted or otherwise processed specially, the separate signal groupings could not be identified. Thus, the peaks P2′ and P3′ might be incorrectly identified as one pair, due to the polarities being reverse. This would result in identification of a different material by means of the computed data and the R/o indicator 20.

As shown in Fig. 7b, the weighted signal Xw can be correctly identified for the different products, because the peaks P1″ and P3″ correspond respectively to the pair P1′-P2′ and the pair P3′-P4′ in Fig. 7a. Thus, even if there is a continuous flow of products, the signals can always be identified for the respective products.

PRIMARY VALUE DETERMINATION

The MPU 15B has a program, as shown in Fig. 8, to determine or recognize "primary values" out of the weighted signals Xw and Yw. The primary values represent the electromagnetic characteristics of an object being inspected.

In order to determine the primary values, it is necessary to monitor a typical change with time of the weighted signal Xw, for example, as shown in Fig. 6. The monitoring span should be three to five times the time interval t1 of the two peaks which occur when foreign matter generates a signal, as shown in Fig. 3c or 4.

As shown in Fig; 9, an appropriate number 2n + 1 of weighted values Xw obtained during a specified time span are constantly monitored. As shown in the following Table 1, the values Xw are stored in order from the newest data to the oldest data as Xi to Xi-2n in a series of memory addresses O-2n.

Table 1

Address	0	1	2 ...	n ...	2n
Data	Xi	Xi-1	Xi-2...	Xi-n ...	Xi-2n

When new data is input to address O, the previous data shift in order from the left to the right, and the oldest data at address 2n is discarded. At each time, the data Xi-n at the central address n is monitored to check whether or not its absolute value is the maximum, or one of several maxima, among the values Xi to Xi-2n at that time (steps 1-2 in Fig. 8)

If it is, the following equation (2) is computed to check whether or not there is an identical maximum value Xi-n$+\alpha$ in the specific vicinity, as generally indicated by the circle A in Fig. 9, of the central address n (step 3).

$0 < |\alpha| \leqq \delta$, Xi-n $+ \alpha =$ Xi-n ? (2)

Provided that the value defines the limit of the vicinity to the central address.

If there is not, Xi-n is determined as the primary value Xp. If there is, Yi-n and Yi-n$+\alpha$ which have the same addresses as those of Xi-n and Xi-n$+\alpha$ are compared. If Yi-n $\geqq$ Yi-n$+\alpha$ (step 4), Xi-n is determined to be the primary value Xp, and the corresponding value Yi-n is determined to be the primary value Yp for the weighted signal Yw.

Conversely, if Yi-n$+\alpha$ is found to be larger than Yi-n, Xi-n is not determined to be the primary value. If this occurs, when Yi-n$+\alpha$ is shifted to the central address n later, that value becomes the maximum value and is thus determined to be the primary value Yp.

If the objects are limited to solid objects or individual batches such as packaged products, because the signals are originally detected individually, the primary values can be obtained without weighting.

For example, as shown in Fig. 10, a positionally adjustable photoelectric or other type of sensor 50 (having an operating time different from that of sensor 26A, 26B in Fig. 1) is provided at an appropriat interval L lengthwise along a belt conveyor 51 with respect to the center of primary coil 3.

As shown in Figs. 12a and 12b, the position and operating time of sensor 50 are preadjusted so that the signal Q generated by the sensor is ON for the time t1 corresponding to one half (e.g. the first half) of the undulating waveform of filtered signals Xf and Yf generated when the object is passed through the coils by the conveyor 51, beginning from the rise of the signal and continuing until the signal reaches the maximum value and then falls past the zero point.

The signals Xf and Yf are input to AND circuits 100 as shown in Fig. 11 together with the passage signal Q, so that the signals Xf and Yf can be detected only while the signal Q is ON. As shown in Figs. 12a and 12b, only the first halves of signals Xf and Yf are detected as signals in the form of a solitary wave similar to the weighted signals.

Subsequently, these signals are converted to digital signals, and primary values can be obtained from the digital signals in the same way as for the weighted signals.

By obtaining the primary values in this way, although there are drawbacks such as the limitation of the objects to packaged types and the need to adjust the position etc. of the sensor, the determination of primary values is simpler than by weighting.

JUDGMENT (IDENTIFICATION)

The MPU 15B has a program for judgement or identification as shown in Fig. 18, which will be explained later.

Fig. 13 shows vectors representing the primary values Xp and Yp for various materials along the x and y axes, respectively.

The phase angle of the vector for iron (Fe) is generally delayed approximately 90 degrees from that of the oscillation signal, and its absolute value or output sensitivity is high. As shown in Figs. 3b and 3c, the y component of the signal for iron is larger in absolute value than the x component.

In contrast, the phase difference of the vectors for stainless steel (SUS) with respect to the oscillation signal is not very large. For some types of stainless steel SUS1 (Fig. 13), both components are positive values. For other types of stainless steel SUS2, the x and y components are respectively positive and negative values.

Some types of materials generate lagging signals like that of iron, and others generate leading signals.

The material effect generally has characteristics and a phase angle which are peculiar to each individual product. Although the size of the vector will change with the content volume of the product, the phase angle will usually not change very much.

Referring to Fig. 14, points P1 (Xp1, Yp1), P2 (Xp2, Yp2), etc. represent the primary values Xp and Yp for various volumes of products of the same type which have material effect, but which contain no foreign matter.

Even if products of the same type differ somewhat in volume or weight, these points will be included in an elliptic region or domain Dm, and will tend to be distributed near and around the central average point Po (μX, μY), which can be represented by a vector rs from the origin point 01 of the coordinate.

The primary values for packages of products of the same type and substantially of the same volume and weight with material effect, but with no foreign matter, will fall within a small circular region Dm′, with its center at the average point Po, due to the vectors being substantially constant in size and angle.

The primary values for a product having material effect and containing even minute particles of foreign matter, such as iron, will be represented at a point Pa (Xa, Ya) as a vector ra. Subtraction of vector rs from vector ra gives a deviation vector Ra from the average point Po.

Thus, the region Dm defines the distribution boundary for products without foreign matter, and data such as point Pa outside this region are judged to represent products which contain foreign matter.

For products having neither material effect nor foreign matter, almost no waveform characteristics as shown in Figs. 3a-3c appear. In this case, random noise resulting from internal electrical factors, such as the operation of the amplifiers, wave detectors or conveyor, becomes the primary factor in determining the distribution region.

As shown in Fig. 15, these products are represented as points P1, P2, etc. within a circular region Dn on the graph. The central average point Po of region Dn is extremely close to the origin point 01. The region Dn is extremely smaller than for products having material effect.

In this case, the size of the deviation vector Ra is approximately the same as that of the signal vector ra. Because of the small size of region Dn, even if the absolute values of these vectors are relatively small, they will extend beyond region Dn. It is thus possible to detect even more minute particles of foreign matter than for products having material effect.

In order to obtain the data needed to determine the regions for various types of objects, there are sample tests in "M" and "N" modes, which have the following characteristics.

M (MATERIAL EFFECT DETECTION) MODE SAMPLE TEST :

This test is carried out for objects which have material effect and contain no foreign matter by obtaining primary values Xp and Yp from samples as "M" mode sample data Xsm and Ysm, such as represented by points P1-P4 in Fig. 14, when the objects pass through the transducer 10. These data include the product

characteristics together with their occasional fluctuations, and also the effects of the various minute amounts of noise which remain even after filtering.

N (NOISE DETECTION) MODE SAMPLE TEST

This test is done for objects which have no material effect and contain no foreign matter, and for which it is difficult to obtain the primary values.

When the passage of a packaged object, for example, through the transducer 1 is detected by the sensor 26A-26B (Fig. 1), a passage signal is generated for a period of time corresponding to the time, 2t1 (Fig. 3c) which is the sum of time t1 preceding the passage of the center of the primary coil 3 by the object and time t1 following it. While this passage signal is being generated, pairs of weighted values Xw and Yw are extracted as "N" mode sample data Xsn and Ysn, respectively, at intervals of a certain number of samples from among the continuous weighted values. For example, 10 to 20 weighted values are extracted for one packaged object. These values Xsn and Ysn may be represented by points P1-P4 in Fig. 15.

Generally, because various types of random noise are a major factor concerning the signals of products which have no product characteristics, the sample values Xsn and Ysn are also random with regard to a time series. It is possible to appropriately extract the characteristics of the amplitude, distribution, etc. of the original random signals from the many data signals obtained by extracting at certain intervals as described above.

The sample values Xsm and Xsn of the M and N modes are generally referred to as a sample value Xs hereinafter, and the values Ysm and Ysn as a sample value Ys.

The sample values Xs and primary values Xp are generally termed representative values X hereinafter, and Ys and Yp as representative values Y.

CORRELATION

For more precise region determination, consideration is given to the correlation of representative values X and Y. Specifically, a correlation coefficient ρ as a factor representing the correlation of values X and Y is included in discriminant equation (5), which determines the region and will be explained later.

The relationship between this correlation coefficient ρ and the region is as follows:

Supposing $X' = X - \mu X$ and $Y' = Y - \mu Y$, in order to find a general expression, if σx and σy are selected for the unit measures of X and Y, and $X'/\sigma x$ and $Y'/\sigma y$ are used for the axes of the coordinate system in order to normalize it, the relationship between the coefficient ρ and the region can be expressed as shown in Fig. 16.

In Fig. 16, the shape or expanse (area) of the region changes with the correlation coefficient. Specifically, if there is no correlation (if $\rho = 0$) between the representative values X and Y, the region is a circle, with widest possible width. Also, the stronger the correlation, the larger the difference between the major and minor axes, and the more elliptic the region, so that the region becomes narrower as the correlation coefficient approaches "1".

If the material effect is small, because the weighted signals Xw and Yw have the characteristics of noise, that is, the sizes and phase of the signals are random and mutually unrelated, as shown in Fig. 15 and explained earlier, when the two-dimensional pairs of representative values X and Y extracted at random from weighted values Xw and Yw, respectively, are plotted on the coordinate system, they are distributed in an approximately circular region.

In other words, in this case, the correlation coefficient ρ is a value approaching zero.

On the other hand, if the material effect is large and the objects are either lumps or have fluctuations in their content volume, although the representative values X and Y which are primary values Xp and Yp will sometimes change momentarily, the ratio of them will maintain an approximately fixed relationship. In other words, because there is correlation between X and Y, the plotting of the pairs of these values on a coordinate system is generally distributed in an elliptical shape as shown in Fig. 14.

Thus, as will be explained later, the discriminant equation which determines the region can be established as a discriminant equation for an elliptical region which includes correlation. By including correlation in the equation, the region can be more narrowly defined than if correlation is not taken into consideration, and defective products which were mistakenly judged to be non-defective when correlation was previously not taken into consideration can be correctly judged to be defective, thus resulting in more accurate judgements. In other words, the introduction of the concept of correlation improves the capacity to judge the presence of foreign matter.

The sample test used to determine the coefficients etc. of the equation is done in the M or N mode. In this test, a large number of pairs of sample data Xs and Ys are obtained, stored in the memory of MPU 15B, and used to compute each of the following values (data for the equation).

μX: average value of Xs
μY: average value of Ys
σx: standard deviation regarding Xs
σy: standard deviation regarding Ys
σxy: covariance regarding Xs and Ys
ρ: correlation coefficient expressed as

$$\frac{\sigma_{xy}}{\sigma_x \cdot \sigma_y}$$

Because the detailed explanations of the symbols listed above are contained in general reference works on statistics, they will be omitted here.

As already explained, the primary values Xp and Yp are used to compute a predetermined discriminant equation, and judgement concerning the presence of foreign matter is made on the basis of whether or not the equation is satisfied. The equation is described below.

Discriminant equation according to the first embodiment (basic discriminant equation)

In the judgement processing, an equation such as the following Equation (4), which is one example of the statistical distribution functions found in reference works on statistics, is used as the density function of the statistical distribution of the data. This equation works both for inspection objects which have material effect and for those which do not, as long as the data is considered to be from the same population.

$$f(x, y) = \frac{1}{2\pi\sqrt{1-\rho^2}\,\sigma_X\sigma_Y} \cdot e^{-\frac{1}{2(1-\rho^2)}\left\{\frac{(X-\mu X)^2}{\sigma_X^2} - 2\rho\frac{(X-\mu X)(Y-\mu Y)}{\sigma_X\sigma_Y} + \frac{(Y-\mu Y)^2}{\sigma_Y^2}\right\}} \quad \ldots\ldots (4)$$

In this embodiment, in order to determine the region condition, the part of the above Equation (4) concerning the exponent of the equation is referred to as "D". This D is a numerical value which determines the region, and it may be determined either based on empirical data, or by the following equation which uses correlation coefficient ρ and the region coefficient d which will be explained later.

$$D = \frac{2}{(1 + \rho)} \cdot d^2$$

Thus, using the above discriminant equation, the following Equation (5) is the basic discriminant equation for determining the region.

$$\frac{1}{(1-\rho^2)} \cdot \frac{(X-\mu X)^2}{\sigma_X^2} - 2\rho\frac{(X-\mu X)(Y-\mu Y)}{(1-\rho^2)\sigma_X\sigma_Y} + \frac{1}{(1-\rho^2)} \cdot \frac{(Y-\mu Y)^2}{\sigma_Y^2} = \frac{2}{1+\rho}\,d^2 \quad \ldots\ldots (5)$$

The region coefficient "d" in the above Equation (5) is input by the region coefficient setting device 24 shown in Fig. 1, which is the input device for this embodiment.

For confidence values of 2σ, 3σ, etc., this coefficient d is as follows.

i) For 2σ,d = 2,

$$D = \frac{2}{1+\rho} \times d^2 = \frac{8}{1+\rho} \quad \ldots\ldots (6)$$

ii) For $3\sigma, d = 3$,

$$D = \frac{2}{1+\rho} \times d^2 = \frac{18}{1+\rho} \quad \ldots\ldots (7)$$

This coefficient d can be appropriately selected by the operator in association with the confidence value. Thus, when the correlation coefficient ρ is calculated and the region coefficient d is selected by the operator, the value of "D", which determines the region, is determined.

In addition, by using the following definitions,

$$A = \frac{1}{(1-\rho^2)\ \sigma_X{}^2}$$

$$B = \frac{-2\rho}{(1-\rho^2)\ \sigma_X \cdot \sigma_X}$$

$$C = \frac{1}{(1-\rho^2)\ \sigma_Y{}^2}$$

Equation (5) can be rewritten as the following Equations (8) and (8)'.

$A(X - \mu X)^2 + B(X - \mu X)(Y - \mu Y) + C(Y - \mu Y)^2 = D$ (8)

$A(X - \mu X)^2 + B(X - \mu X)(Y - \mu Y) + C(Y - \mu Y)^2 - D \leqq 0$ (8)'

Equation (8) determines the boundary of the distribution region, and Equation (8)' is the discriminant equation which judges whether or not the data is included in the region.

As explained earlier, because Equation (8) defines an elliptical or circular region, depending on the value of the correlation coefficient ρ, it is applicable to both products which have material effect and those which do not.

Equation (8)' is included in the MPU 15B in the form of a program, and computed for each pair of primary values Xp and Yp at final inspection of objects.

Theoretically, the region discriminant equation can be determined by the operator selecting and inputting appropriate values A, B and C, and the region coefficient d in accordance with the characteristics of the object. However, because it is not easy to select these values, provision has been made in this embodiment to simplify the operator's selection tasks.

Specifically, instead of providing a device to input the values A, B and C, the MPU 15B has a program whereby, when the operator uses the switch 18 to select the equation computation mode, the data which was obtained and stored in the previous sample test is recalled, the statistical quantities μX, μY, σx, σy, ρ, etc. are automatically computed, and the values A, B and C are also automatically computed.

The program further computes the value D in Equation (8) with these computed results when the region coefficient d is input by the operator via the device 24. This determines all coefficients of discriminant Equation (8)' to specify this equation. In this way, the automatic setting for the region discriminant Equation (8)' is completed.

Discriminant equation according to the second embodiment

Instead of the discriminant equation for the above mbodiment, it is also possible to use the discriminant equation described below. The embodiment using this equation will be explained as a second embodiment with regard to the discriminant equation.

If the inspection objects have an approximately constant volume or a fixed size, such as for packaged

products, even if the objects have material effect, because the major axis of the elliptical distribution of the characteristics becomes shorter and the shape approaches that of a circle, the following Equations (5a) and (8a) can be used in place of the Equations (5) and (8).

$$\frac{(X-\mu X)^2}{\sigma_X{}^2} + \frac{(Y-\mu Y)^2}{\sigma_Y{}^2} = 2d^2 = D' \quad \ldots\ldots (5a)$$

This Equation (5a) is applicable when $\rho = 0$ in the first embodiment already described.

Here, with the following definitions,

$$A' = \frac{1}{\sigma_X{}^2}$$

$$C' = \frac{1}{\sigma_Y{}^2}$$

Equation (5a) can be used to determine the following Equation (8a)′ as the discriminant equation.

$A'(X - \mu X)^2 + C'(Y - \mu Y)^2 - D' \leqq 0$ (8a)′

This case is equivalent to not taking the correlation into consideration, in other words, not using the correlation coefficient (ρ). In addition, just as in the first embodiment, it is also possible to assign a direct numerical value for D′ using an empirical value. Discriminant equation according to the third embodiment

Furthermore, instead of the discriminant equations described above for the first and second embodiments, it is also possible to use the discriminant equation described below. The embodiment using this discriminant equation will be explained as a third embodiment with regard to the discriminant equation.

In other words, just as for the second embodiment 20 described above, if the inspection objects are of an approximately constant volume or fixed size, such as packaged products, when the measurement data (primary values) P1-P4, etc. of a typical inspection object are plotted on an x-y coordinate system, they are gathered together in the vicinity of a specific location on the coordinate system, as shown in Fig. 17.

These data can be considered to be distributed within a closed range of predetermined spreads of $\pm d.\sigma x$ $(= \pm Dx)$ and $\pm d.\ \sigma y(= \pm Dy)$ in the positive and negative directions with respect to the average values μX and μY along the x and y axes, respectively. This derives the following Equations (5b) and (5c).

$\mu X - D_x \leqq X \leqq \mu X + D_x$ (5b)

$\mu Y - D_y \leqq Y \leqq \mu Y + D_y$ (5c)

The above Equation (5b) and (5c) can be transformed to obtain the following Equations (8b)′ and (8c)′.

$|X - \mu X| - D_x \leqq 0$ (8b)′

$|Y - \mu Y| - D_y \leqq 0$ (8c)′

Equations (8b)′ and (8c)′ are the discriminant equations, and objects which satisfy both of these equations are non-defective products containing no foreign matter. On the other hand, objects which fail to satisfy either one or both of these equations are judged to be defective products containing foreign matter. An illustration of the region determined by these equations appears as a region enclosed within a rectangle, as shown in Fig. 17. In other words, non-defective and defective products fall respectively in and outside the region.

In Fig. 17, the distance between the central point Po of the region and the origin point 01 of the coordinate system represents the average size of the material effect of the product. Thus, for objects having no material effect, these points Po and 01 are the same.

Discriminant equations (8b)′ and (8c)′ are also programmed in the control device 15. The correlation coefficient ρ is also not taken into consideration for this third embodiment. The values Dx and Dy may also be empirical values.

As explained above, the operator operates the following devices:

the device 24 to specify the region coefficient d;

the numeric keys of keyboard 25 (Fig. 1) to specify the code number for the type of object;

the command key Mi of keyboard 25 to input and store in the MPU 15B with the code number the various coefficients, such as A-D for the first embodiment, A′, C′ and D′ for the second embodiment, or Dx and Dy for the third embodiment, and the statistical quantities μX and μY of the discriminant equation/s computed with the data obtained from the sample test results and with the coefficient d input by the operator; and

the command key Mo to r call with the code number the data when the same discriminant equation is to be used on a subsequent occasion.

Through these operations, various coefficients, statistical quantities, tc. related to each of a plurality of

different product types are stored during the first inspection, and, if a product of one of these types is to be inspected again, the relevant information can be recalled and instantly used.

OPERATION

The following is an explanation of the procedures involved in the detection of foreign matter.

PRELIMINARY PROCEDURES

(1) Test Operation

The operator sets the selector switch 18 to the sample test mode. At the same time, the R/φ indicator 20 is set to indicate the absolute value r and phase angle θ of a vector r from the origin point on the coordinate system (Fig. 14, 15). The values r and θ are calculated with weighted values Xw and Yw as follows. $r = \sqrt{Xw^2 + Yw^2}$

$$\theta = \frac{180}{\pi} \cdot \tan^{-1} \frac{Yw}{Xw}$$

In this way, the operator is able to continuously monitor the indication values during no-load operation and the subsequent sample test.

First, a no-load test operation is performed to find the noise level of the apparatus itself on the indicator 20.

Next, the operator selects a number of samples, which have been determined to be free of foreign matter, from a type of objects to be inspected. He puts the samples to be passed through the coils, reads the absolute values on the indicator 20, and determines whether or not the values have increased from those during the no-load operation.

If the values are clearly larger than the noise level, it is judged that there is material effect, and the subsequent sample test is carried out in the M mode. If not, it is judged that there is no material effect, and the sample test is carried out in the N mode.

(2) Sample Test

The operator sets the selector switch 23 to either the M or N mode, presses the execution button 21, selects a large number of samples having no foreign matter from that type of objects, and puts the samples to be passed through the coils. As a result, regardless of which mode was used, the data for the samples is stored in the MPU 15B.

(3) Discriminant Equation Determination (Specifying)

When the operator sets the switch 18 to the equation computation mode and presses the execution button 21, the values μX, μY, σx, σy, ρ, etc. for the samples are computed as described earlier with the data obtained in the sample test.

For the first embodiment, the equations for the values A, B and C are then calculated to determine the coefficients for the left side of Equation (8).

When the operator inputs the appropriate region coefficient d, the value D which determines the region conditions is calculated, and the discriminant equation (8)′ is specified. This completes the preparations for the computation of the discriminant equation for the first embodiment.

For the second and third embodiments as well, the equations (8a)′ or (8b)′ and (8c)′ are determined likewise.

The values D, D′ Dx, Dy, etc. can be found by calculating as explained, or, if empirical values are known, they can be input directly.

(4) Storage of Coefficients and Statistical Quantities

When the operator completes the equation determination, it is possible, instead of proceeding directly to actual operation, to store the coefficients and statistical quantities for the discriminant equation peculiar to each type of objects and recall them at any time, as explained earlier.

Specifically, the operator stores the values A, B, C, D, μX, μY, etc. for the particular discriminant equation by inputting the code number for the type of objects via the keyboard 25 and then pressing its memory key Mi, and recalls the data when needed by inputting the same code number and then pressing the key Mo.

Thus, in actual operation, by specifying a code number for various data pertaining to a particular type of object and storing it, part of the preliminary procedures can be eliminated during subsequent inspection work.

ACTUAL OPERATION

Actual operation begins once the preliminary procedur s have been completed. During actual operation, the R/φ indicator 20 is set to indicate the absolut value R and phas angle φ of a deviation vector R, which are computed by Equations (11) and (12) below with the primary values Xp and Yp.

When the operator sets the switch 18 to the operation mode for actual operation, the program control circuit

17 inputs the program for inspection of objects to the MPU 15B. In this mode, the judgement section of MPU 15B receives the data in the M mode.

The operator presses the execution button 21, and passes through the transducer 10 objects the samples of which have been tested, but it is unknown whether or not the objects contain foreign matter. If the transducer 10 outputs a signal XY as shown in Fig. 3a for one object, it is processed through th various devices and input to the MPU 15B.

In the MPU 15B, a pair of primary values Xp and Yp are obtained by the program of Fig. 8. Even during this processing, other objects are continuously detected (parallel processing).

As shown in Fig. 18, the following equations are then computed with the primary values, and the results are indicated in the R/φ indicator 20. $R = \sqrt{(Xp = \mu X)^2 + (Yp - \mu Y)^2}$ (11)

$$\phi = \frac{180}{\pi} \cdot \tan^{-1} \frac{(Y_p - \mu Y)^2}{(X_p - \mu X)^2} \quad \ldots\ldots (12)$$

As mentioned earlier, the values μX and μY are the average sample values obtained in the sample test in the M or N mode, and the values A-D, or A′, C′ and D′, or Dx and Dy in the discriminant equation/s (8)′, (8a)′, or (8b)′ and (8c)′ have been predetermined in the preliminary procedures.

The equation/s is/are then computed with the values Xp and Yp substituted for X and Y, respectively. If the result satisfied the equation (i.e., the left side is 0 or negative), the data is judged to be in the region. If the equation is not satisfied, the data is judged to be outside of the region.

If the data is outside the region, the alarm 19 is activated to warn that the object has not passed the inspection, and a sorting device (not shown) further down the line is commanded to remove the object.

With this method, when an object contains water, salt or the like and has a material effect, if the amount of the contained material varies, the electromagnetic characteristics will change and the region conditions of the reference object (standard product) will not be satisfied. This will cause a signal which indicates that the object is defective to be generated. Thus, this method may be effective for use in quality control.

The R/φ indicator 20 may be adapted to indicate the type of material effect of the object, or the type of foreign matter (metal, iron or non-ferrous metal, etc.) which has been detected in the object, as shown in Fig. 13.

ADVANTAGES OF DETECTOR WITH JUDGEMENT SECTION

(1) Because the data obtained in the sample test is automatically computed to determine the judgement conditions, the determination of the judgement conditions is almost completely automatic. In addition, because the data is stored after it is collected and can then be recalled and used again for the same inspection object, there is no need to collect the data for the inspection object at that time.

(2) The operator only has to consider such things as whether to select a confidence level of 2σ or 3σ in order to determine the region coefficient, and there is no need for adjustments which require skilled expertise, such as phase adjustments of the excitation signal or signal detection reference signal, as are required in prior art detectors.

(3) It is possible to achieve a remarkable improvement over prior art detectors in the precision of the detection of foreign matter which is contained in inspection objects having material effects.

(4) It is possible to inspect more types of inspection objects than with prior art foreign matter detectors of this type, thus increasing the range of inspection applicability. In other words, regardless of whether the inspection objects are separate or packaged, and also regardless of whether they have material effect or not, the detector of this invention can be set and used according to a fixed procedure without being affected by the configuration or characteristics of the inspection objects.

General Advantages of the Invention

With this invention, as described above, it is possible to perform accurate detection even if the inspection object has material effect, and also even if the inspection object contains minute particules of metal which react in the same phase as that material effect.

Moreover, by knowing in advance the relationship between the type of metal and the phase, it is also possible to detect the type and size (quantity) of the metal. Also, because there is no need for precise trial-and-error adjustments of either the phase or the sensitivity, as was required in prior art detectors, this detector can be easily operated by anyone without requiring extended preparations.

Thus, damage to processing equipment which might result from the presence of foreign matter in raw materials, etc. is prevented, and, furthermor , the shipment of products etc., containing foreign matter is also prevented.

In addition, because the detection signals contain not only data on whether or not foreign matter is present, but also quantitative data as well, the detection of foreign matter or of quality differences is easily accomplished. Thus, with this detector, it is also possible to detect instances where the quality of the product

differs from the specified level.

Furthermore, because the composition is simple, the detector can be provided at a lower cost than the prior detectors described herein, and maintenance and adjustments can be easily performed.

Even if metal or other foreign matter is contained inside an inspection object having material effect and that foreign matter has a phase of the same direction as the phase direction of said material effect, because the two-dimensional pair of digital primary value signals for the inspection object is computed and identified using a discriminant equation which has been predetermined in consideration of that material effect of the inspection object, identification can be performed with greater sensitivity than possible using a detector of the prior art.

For the same reason as above, even if there is noise generated by the device, the detection of metals and other foreign matter can be performed without being affected by that noise.

Because the detection signals are expressed by two coordinates (i.e., in a two-dimensional plane) the type and size of metal can be easily identified, and even foreign matter which generates no more than a small signal can be detected.

Claims

1. A detector comprising:
means (1 to 10) for providing a two-dimensional pair of analog signals representative of electromagnetic parameters of an object;
means (11,12) for converting said analog signals into respectively a first and a second series of digital values;
means (14,15) responsive to said two series of digital values for determining respective representative values X and Y; and
computation means (15) for performing a computation based on the following discriminant equation(s) (i), or (ii) in order to determine whether the conditions expressed thereby are met:
(i) $A'(X-\mu X)^2 + C'(Y-\mu Y)^2 - D' \leq 0$
where the coefficients A′, C′, D′, μX, and μY are values approximately selected for the object;
(ii) $|X-\mu X| - Dx \leq 0$ and
$|Y-\mu Y| - Dy \leq 0$
where the coefficients μX, μY, Dx and Dy are values appropriately selected for the object.

2. A detector as claimed in claim 1, wherein the converting means (11,12) is capable of providing a plurality of sets of first and second digital values, each set being produced in response to analog signals representative of electromagnetic parameters of a respective sample of said object; wherein, with regard to equation (i):

$$A' = \frac{1}{\sigma X^2}$$

$$C' = \frac{1}{\sigma Y^2}$$

$D' = 2d^2$; wherein, with regard to equation (ii):
$Dx = d.\sigma x$
$Dy = d.\sigma y$
and wherein:
μX and μY are averages of representative values X and Y, respectively, for the samples; and
σx and σy are respectively standard deviation values of X and Y for the samples;
the detector further comprising means (15) for obtaining the values of said coefficients μX and μY, together with A′, C′ and D′ or Dx and Dy, from said sets of first and second digital values and a value d appropriately selected for said object.

3. A detector as claimed in claim 2, including means (15,25) permitting storage of data defining coefficients to be used in a discriminant equation together with a code associated with the type of object to which the coefficients relate, thereby permitting later retrieval of said data by entry of said code number.

4. A detector comprising:
means (1 to 10) for providing a two-dimensional pair of analog signals representative of electromagnetic parameters of an object;
means (11,12) for conv rting said analog signals into respectively a first and a second series of digital values;
means (14,15,50) for deriving from said first and second series of digital values respective representative values X and Y, said deriving means including means (50) for generating a passage signal while said

object is passing through a predetermined region during which said analog signals are provided, and means (15) for selecting said representative values X and Y from said two series of digital values produced while said passage signal is generated; and

comparing means (15) for comparing said representative values X and Y selected while said passage signal is generated with predetermined reference values.

5. A detector as claimed in claim 4, wherein said providing means (1 to 10) is so arranged that the analog signal each adopt values which differ in a first sense from an initial value as the object travels through a first part of its path and which differ in a second, opposite sense from the initial value as the object travels through a second part of its path, and wherein said predetermined region corresponds to one of said parts of the object's path.

6. A detector as claimed in claim 4 or 5, including means (15,25) for storing a plurality of sets of reference values, each set relating to a respective type of object, said means (15,25) permitting retrieval of each set in response to entry of a respective code.

7. A detector comprising:

means (1 to 10) for providing a two-dimensional pair of analog signals representative of electromagnetic parameters of an object;

means (11,12) for converting said analog signals into respectively a first and a second series of digital values;

means (14,15) for deriving from said first and second series of digital values respective representative values X and Y;

means (15,25) permitting storage and retrieval of a selected one of a plurality of stored sets of reference values, each set being associated with a respective type of object; and

comparing means for comparing the representative values X and Y with the retrieved set of reference values.

8. A detector according to any one of claims 4, to 7, wherein said comparing means (15) is operable to compare the representative values X and Y with reference values by determining whether the conditions expressed by one or more discriminant equation(s) are met.

9. A detector according to claim 8, wherein said equation is:

$$A(X - \mu X)^2 + B(X - \mu X)(Y - \mu Y) + C(Y - \mu Y)^2 - D \leqq 0$$

where the coefficients A, B, C, D, μX and μY are values appropriately selected for the object.

10. A detector according to claim 8, wherein said equation is:

$$A'(X - \mu X)^2 + C'(Y - \mu Y)^2 - D' \leqq 0$$

where the coefficients A′, C′, D′, μX, and μY are values appropriately selected for the object.

11. A detector according to claim 8, wherein said equations are:

$$|X - \mu X| - Dx \leqq 0$$

$$|Y - \mu Y| - Dy \geqq u$$

where the coefficients μX, μY, Dx and Dy are values appropriately selected for the object.

12. A detector comprising:

means (1 to 10) for providing a two-dimensional pair of analog signals representative of electromagnetic parameters of an object;

means (11,12) for converting said analog signals into respectively a first and a second series of digital values;

means (14,15) responsive to said two series of digital values for determining respective representative values X and Y; and

computation means (15) for performing a computation based on the following discriminant equation(s) (i), (ii) or (iii) in order to determine whether the conditions expressed thereby are met:

(i) $A(x - \mu x)^2 + B(X - \mu X)(Y - \mu Y) + C(Y - \mu Y)^2 - D \leqq 0$;

(ii) $A'(X - \mu X)^2 + C'(Y - \mu Y)^2 - D' \leqq 0$;

(iii) $|X - \mu X| - Dx \leqq 0$ and

$|Y - \mu Y| - Dy \leqq 0$;

the detector futher comprising means (15,25) permitting storage of the coefficients A, B, C, D, μX, μY, or A′, C′, D′, μX and μY, or μX, μY, Dx and Dy and subsequent retrieval thereof for use by said computation means (15).

13. A detector as claimed in claim 12, wherein the converting means (11,12) is capable of providing a plurality of sets of first and second digital values, each set being produced in response to analog signals representative of electromagnetic parameters of a respective sample of said object;

wherein, with regard to equation (i):

$$A = \frac{1}{(1-\rho^2)\sigma x^2}$$

$$B = \frac{-2\rho}{(1-\rho^2)\sigma x \sigma y}$$

$$C = \frac{1}{(1-\rho^2)\sigma y^2}$$

$$D = \frac{2}{(1+\rho)} . d^2 ,$$

wherein, with regard to equation (ii):

$$A' = \frac{1}{\sigma x^2}$$

$$C' = \frac{1}{\sigma y^2}$$

$$D' = 2d^2 ;$$

wherein, with regard to equation (iii):
$Dx = d.\sigma x$
$Dy = d.\sigma y$
and wherein:
μX and μY are averages of representative values X and Y, respectively, for the samples;
σx and σy are respectively standard deviation values of X and Y for the samples; and
ρ is a correlation coefficient of X and Y for the samples;
the detector further comprising means (15) for obtaining the values of said coefficients μX and μY, together with coefficients A, B, C, and D, or A′, C′ and D′, or Dx and Dy, from said sets of first and second digital values and a value d appropriately selected for said object, thereby permitting subsequent storage of said coefficients.

14. A detector as claimed in claim 12 or 13, wherein said means (15,25) permitting storage is arranged to allow a plurality of sets of coefficients, each set being associated with a respective type of object, to be stored and subsequently selectively retrieved.

15. A detector according to any preceding claim, wherein the providing means (1 to 10) comprises:
an oscillator (1) for generating a basic oscillating signal;
a phase shifter (8) connected to said oscillator (1) and adapted to provide a phase-shifted oscillating signal;
an electromagnetic transducer (10) including an excitation coil (3) connected to said oscillator (1), and two interconnected detection coils (4,5) magnetically coupled to said excitation coil and adapted to produce a differential signal therebetween when an object is passed through said transducer (10);
a first detector (7A) connected to said detection coils (4,5) and said oscillator (1) and adapted to produce a first detected analog signal representing the component of said differential signal in phase with said basic oscillating signal; and
a second detector (7B) connected to said detection coil (4,5) and said phase shifter (8) and adapted to produce a second detected analog signal representing the component of said differential signal in phase with said phase-shifted oscillating signal.

FIG.1.

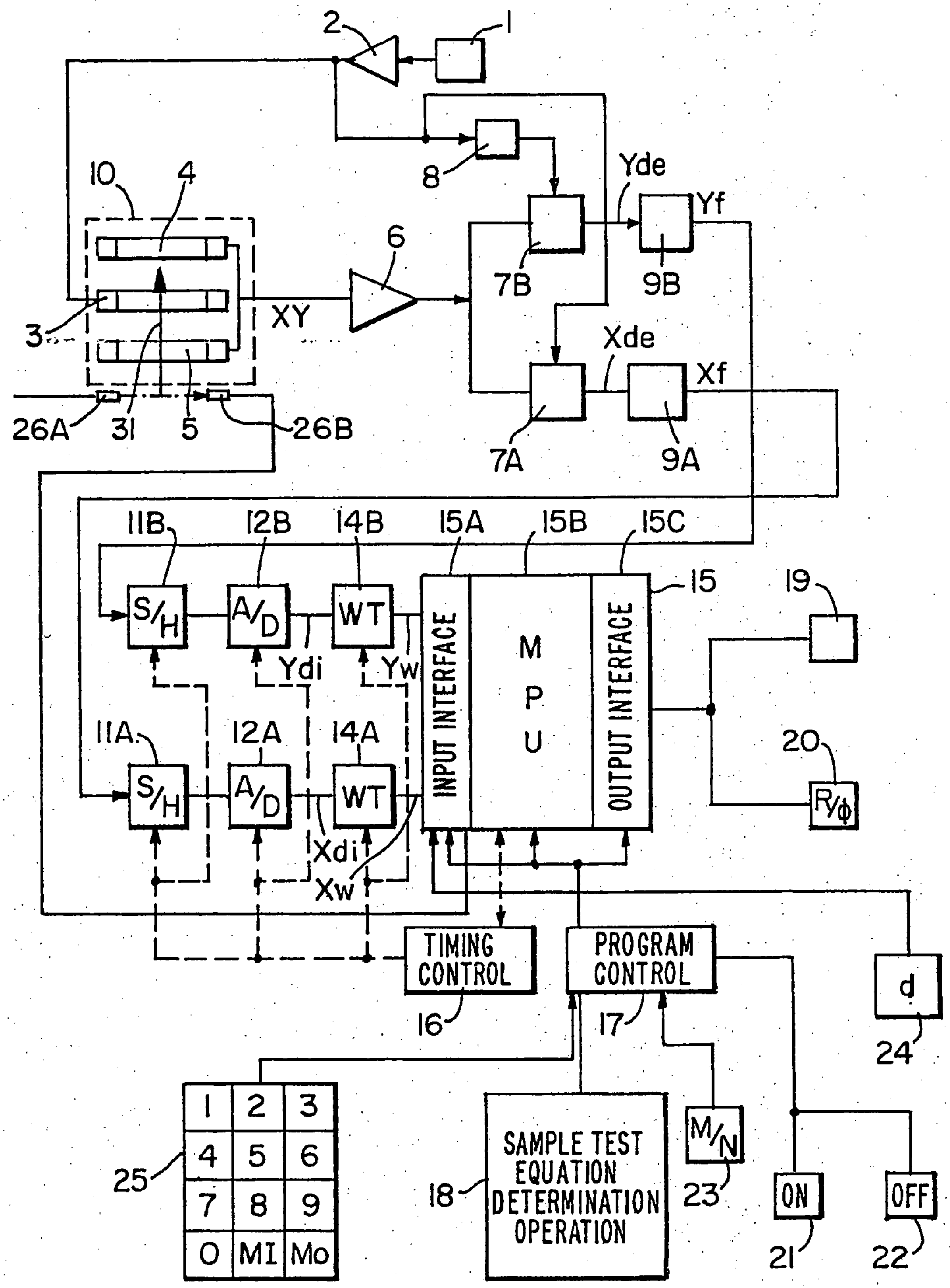
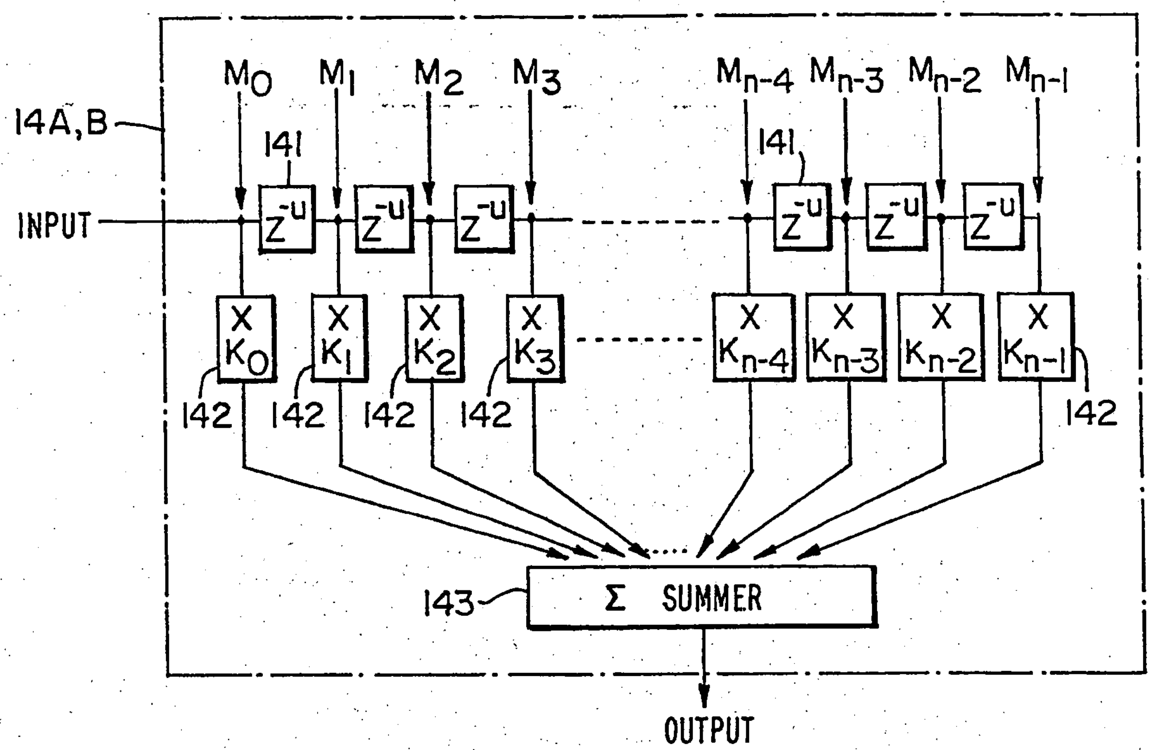

1
2
8
Yde
Yf
10
4
6
7B
9B
3
XY
Xde
Xf
26A
31
5
26B
7A
9A
11B
12B
14B
15A
15B
15C
15
19
S/H
A/D
WT
INPUT INTERFACE
M P U
OUTPUT INTERFACE
Ydi
Yw
11A
12A
14A
20
R/φ
Xdi
Xw
TIMING CONTROL
PROGRAM CONTROL
d
16
17
24
1 2 3
4 5 6
7 8 9
O MI Mo
25
SAMPLE TEST EQUATION DETERMINATION OPERATION
18
M/N
23
ON
OFF
21
22

FIG. 2.



14A,B
INPUT
M_0
M_1
M_2
M_3
M_{n-4}
M_{n-3}
M_{n-2}
M_{n-1}
141
141
Z^{-u}
X K_0
X K_1
X K_2
X K_3
X K_{n-4}
X K_{n-3}
X K_{n-2}
X K_{n-1}
142
143
Σ SUMMER
OUTPUT

FIG.3a.

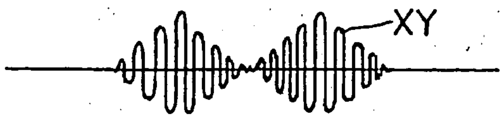


FIG.3c.

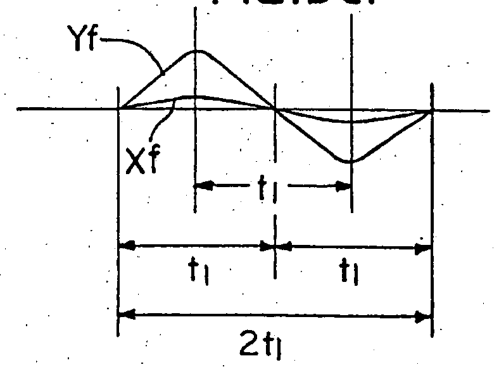


FIG.3b.

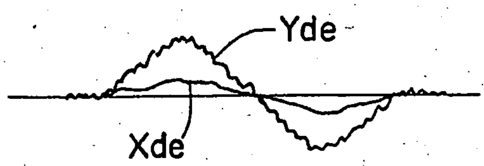


FIG.14.

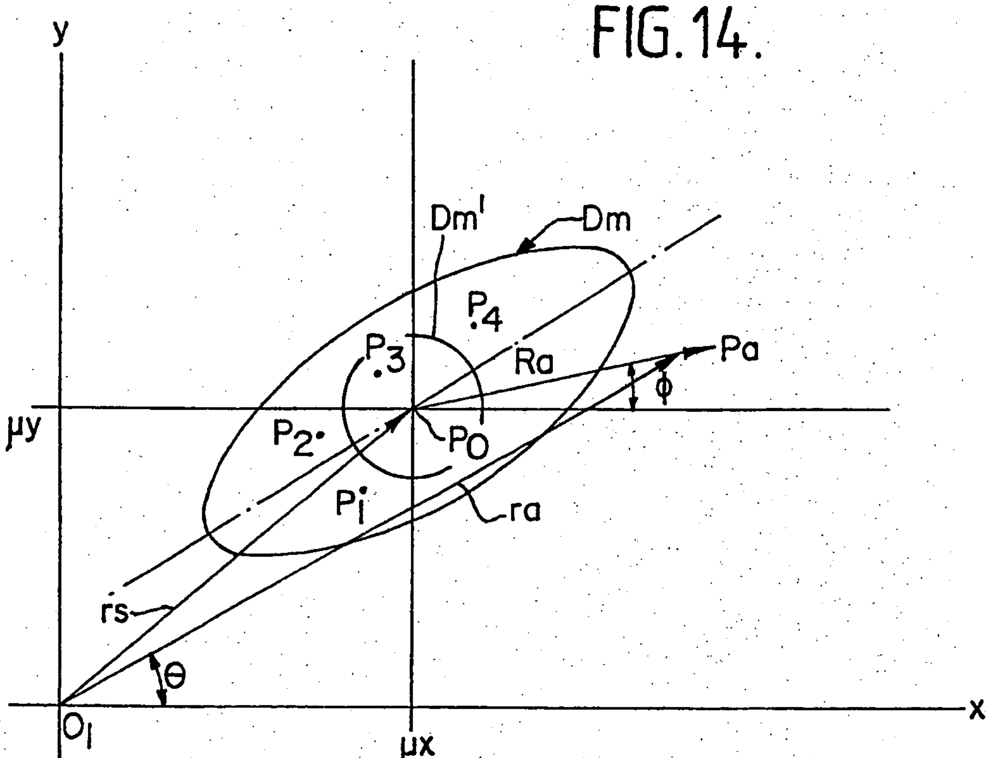


FIG.4.

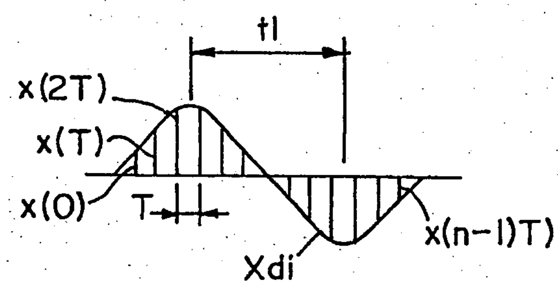


FIG.5a.

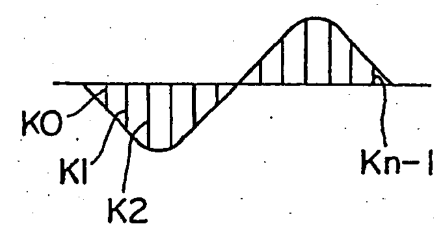


FIG.5b.

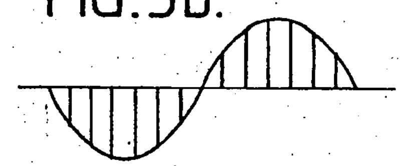


FIG.6.

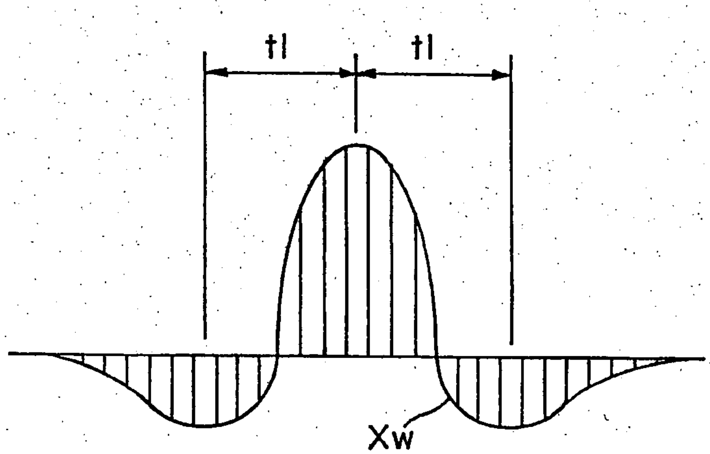
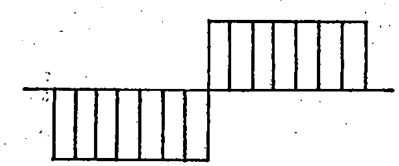


FIG.5c.



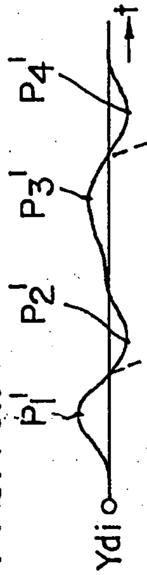


FIG.7a.

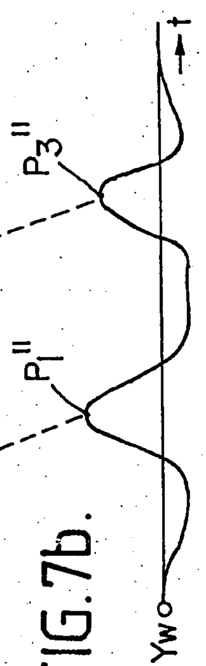


FIG.7b.

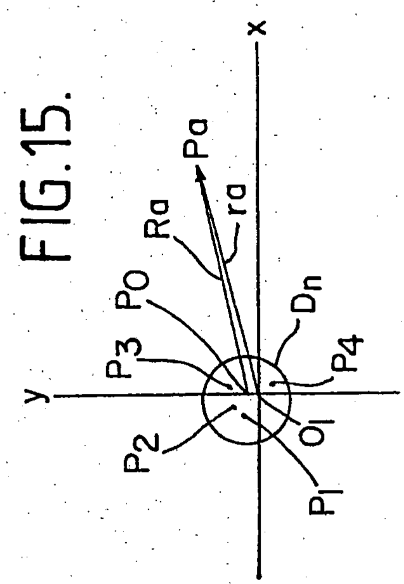


FIG.15.

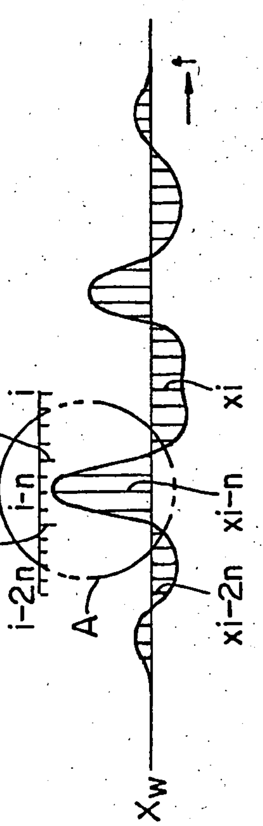


FIG.9.

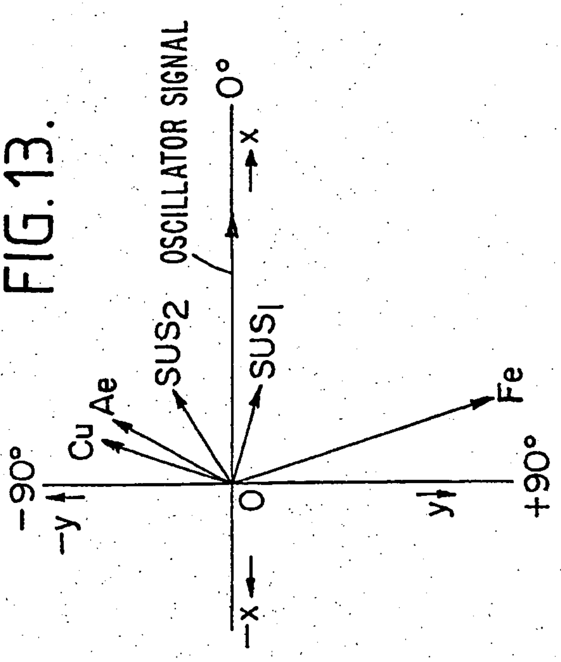


FIG.13.

FIG.8.

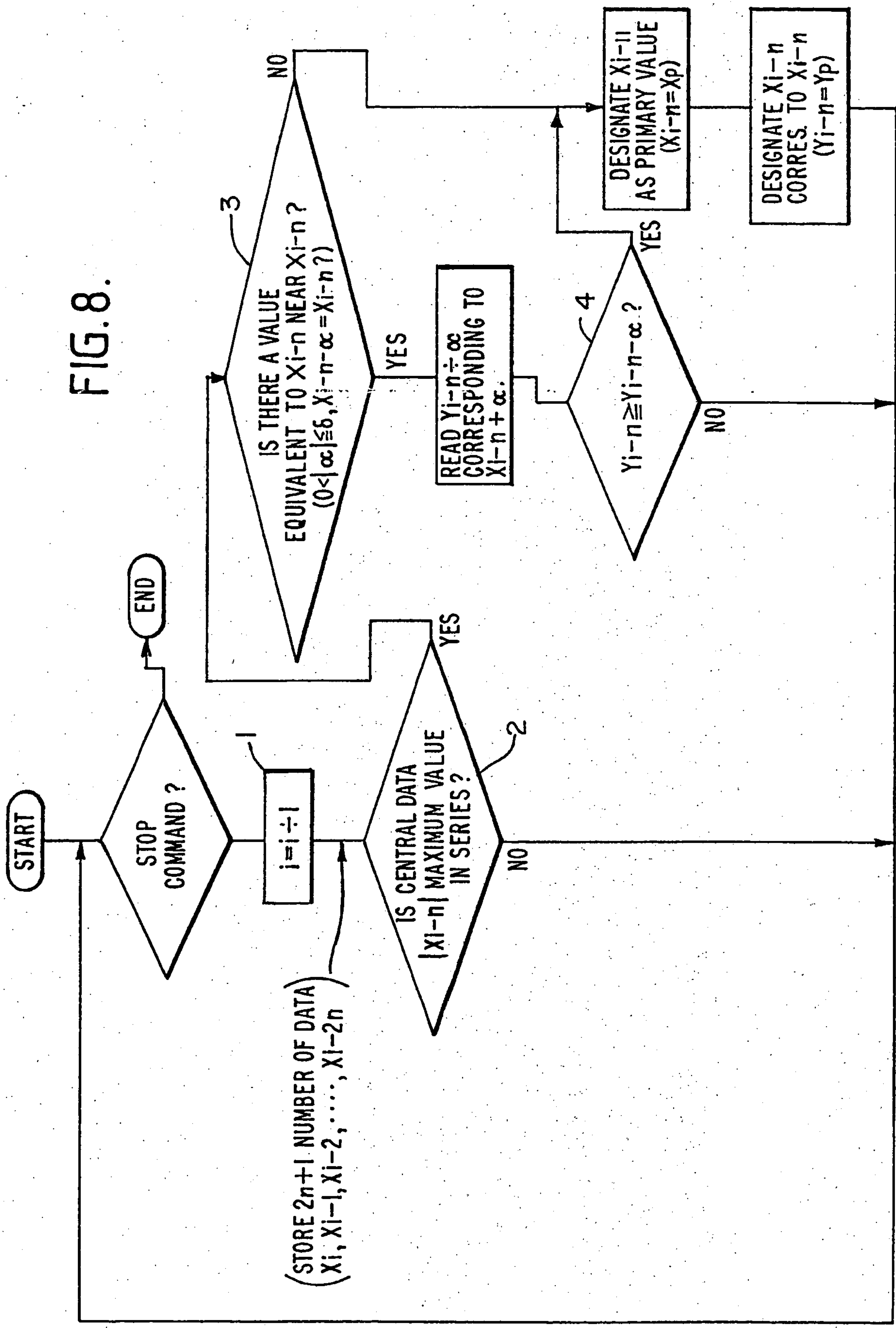

START
STOP COMMAND ?
END
1
i=i+1
(STORE 2n+1 NUMBER OF DATA Xi, Xi-1, Xi-2, ···, Xi-2n)
2
IS CENTRAL DATA |Xi-n| MAXIMUM VALUE IN SERIES ?
YES
NO
3
IS THERE A VALUE EQUIVALENT TO Xi-n NEAR Xi-n ? (0<|α|≤δ, Xi-n-α=Xi-n ?)
YES
NO
READ Yi-n+α CORRESPONDING TO Xi-n+α.
4
Yi-n≧Yi-n-α ?
YES
NO
DESIGNATE Xi-n AS PRIMARY VALUE (Xi-n=Xp)
DESIGNATE Yi-n CORRES. TO Xi-n (Yi-n=Yp)

FIG.10.

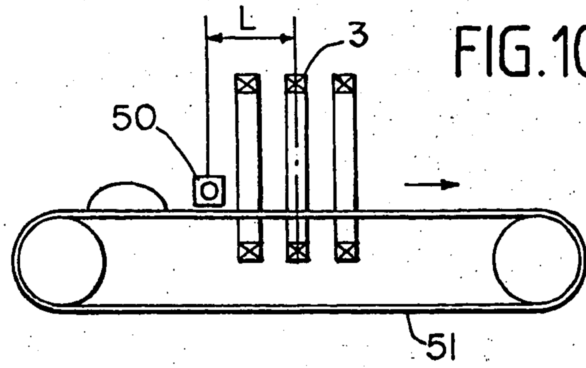


FIG.11.

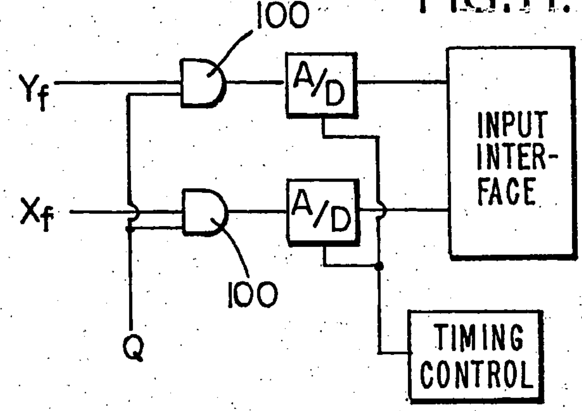


FIG.12a.

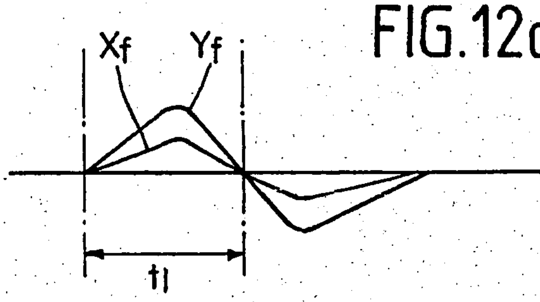


FIG.12b.

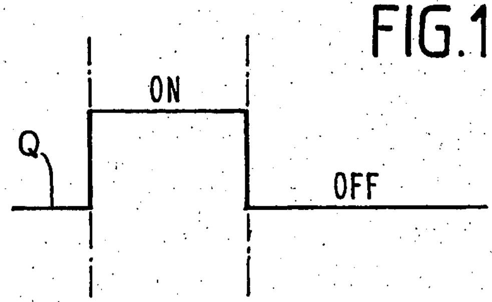


FIG.16.

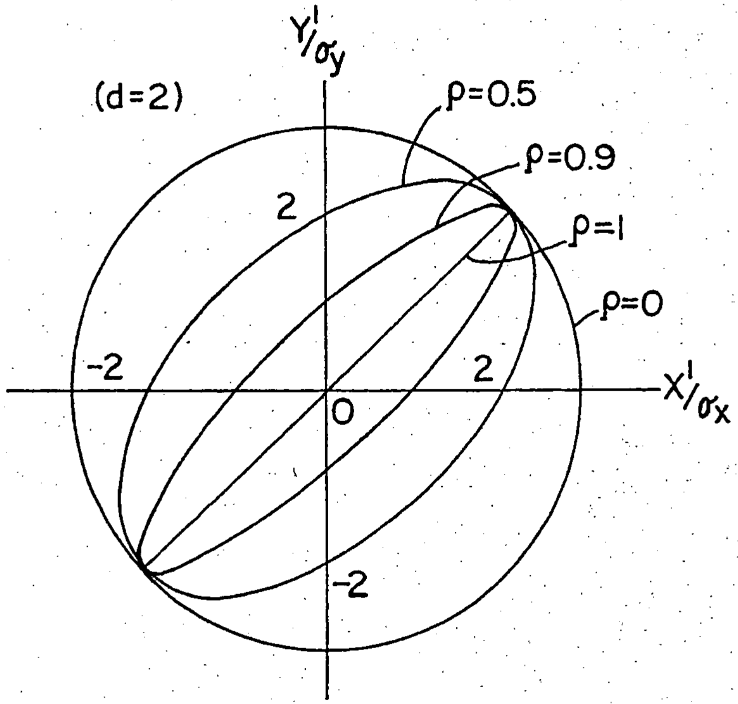
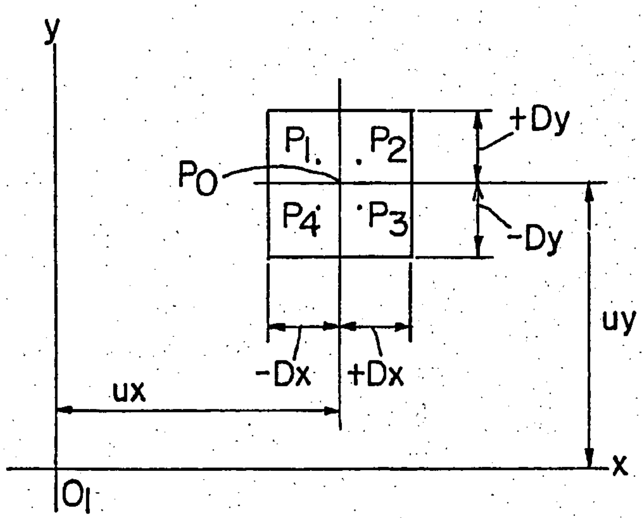


FIG.17.



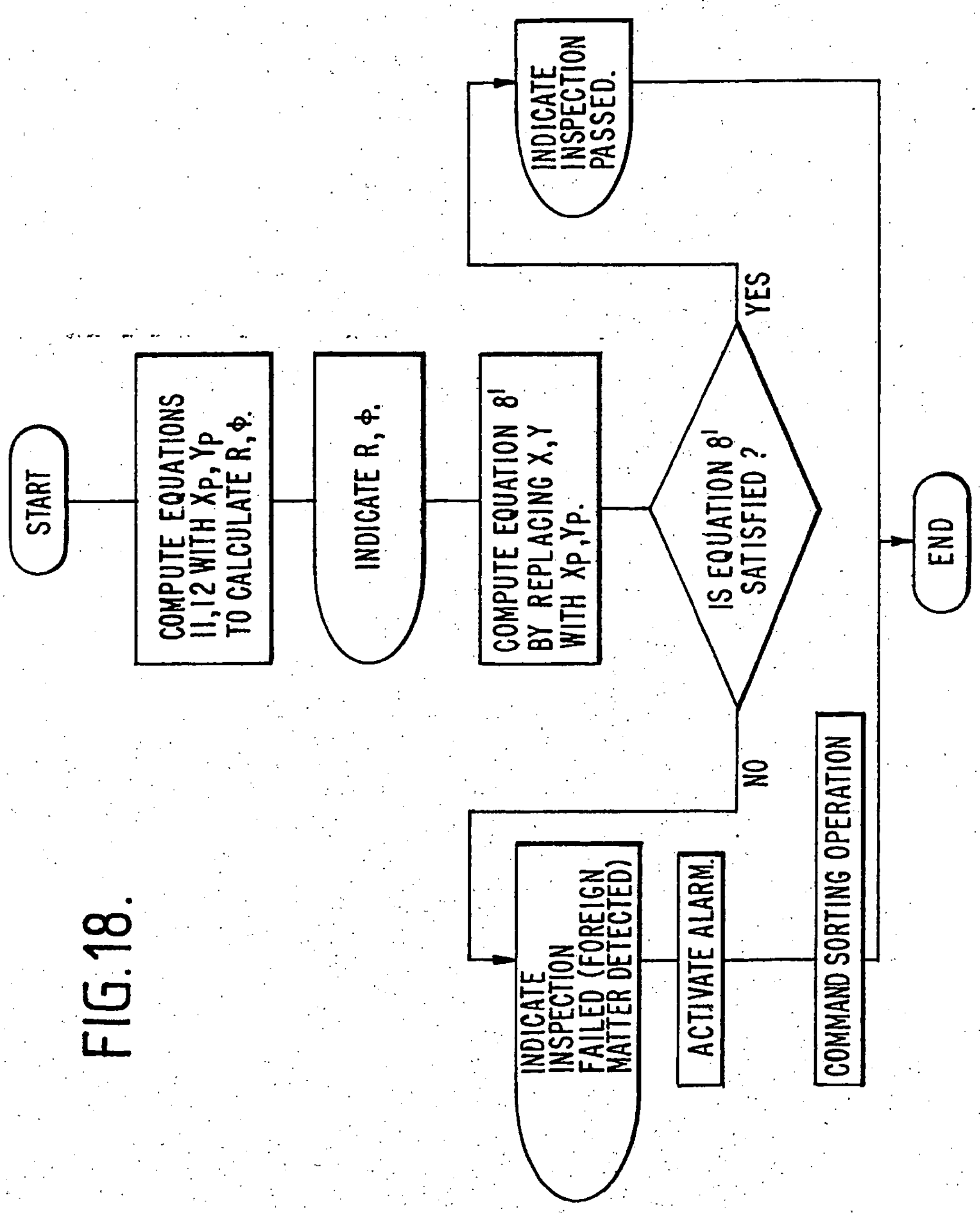

START
COMPUTE EQUATIONS 11,12 WITH Xp, Yp TO CALCULATE R, Φ.
INDICATE R, Φ.
COMPUTE EQUATION 8' BY REPLACING X,Y WITH Xp, Yp.
IS EQUATION 8' SATISFIED ?
YES
NO
INDICATE INSPECTION PASSED.
INDICATE INSPECTION FAILED (FOREIGN MATTER DETECTED)
ACTIVATE ALARM.
COMMAND SORTING OPERATION
END

FIG.18.

FIG.19.
PRIOR ART

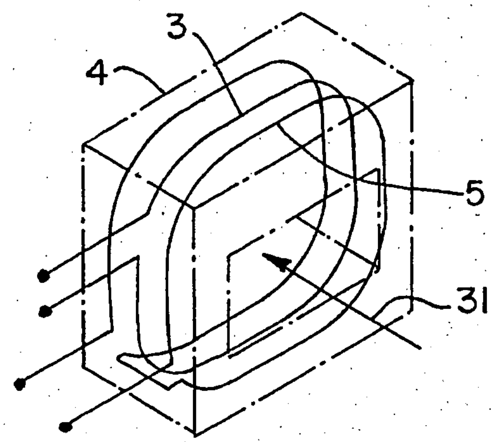


FIG.20.
PRIOR ART